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VLF/LF REFLECTIVITY OF THE POLAR IONOSPHERE,
AUG 76 J E RASMUSSEN, R J MCLAIN, J P TURTLE

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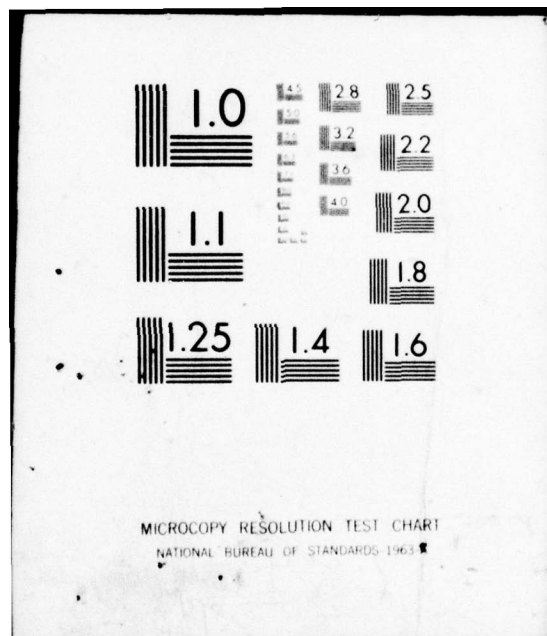
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AUGUST 1976

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VLF/LF Reflectivity of the Polar Ionosphere 4 May - 5 July 1975

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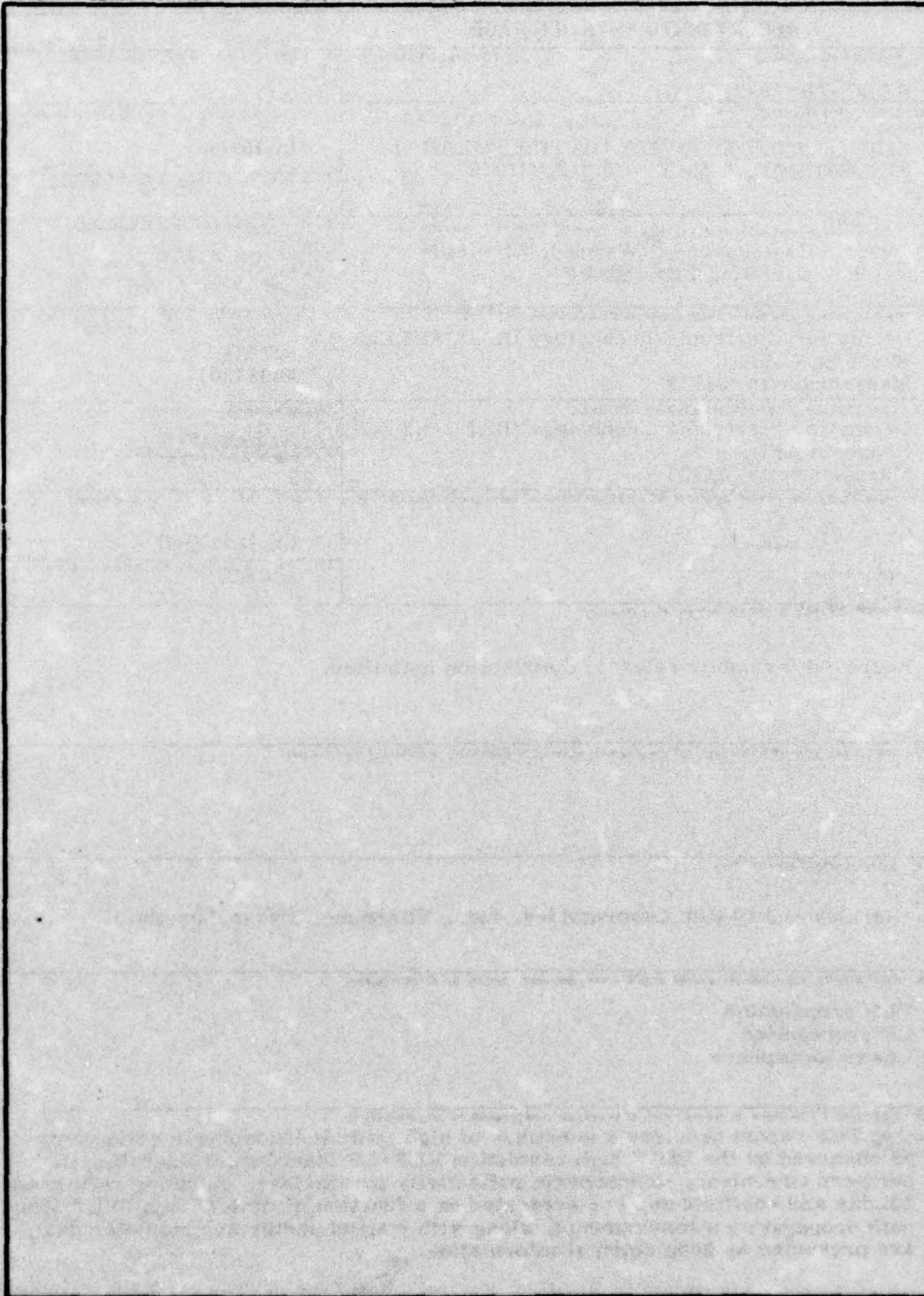
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Preface

The authors thank in particular Dr. Edward A. Lewis for valuable discussions on preparing this paper, Mr. Royce C. Kahler of Barkley & Dexter Labs for help with the equipment that made the measurements possible, and Mr. Jens Ostergaard of the Danish Meteorological Institute for the outstanding operation at Qanaq, Greenland.

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VLF/LF Reflectivity of the Polar Ionosphere

4 May—5 July 1975

1. INTRODUCTION

This paper provides a summary of high latitude ionospheric reflectivity, as observed by the USAF's high resolution VLF/LF ionosounder operating in northern Greenland.^{1,2,3,4} As shown in Figure 1, the transmitter is located at Thule Air Base, Greenland (76° 33'N. Lat., 68° 40'W. Long.), and the receiving site is 106 km north at the Danish Meteorological Institute's Ionospheric Observatory in Qanaq, Greenland (77° 24'N. Lat., 69° 20'W. Long., Geomagnetic Lat. 89° 06' N.). The ionosounding transmissions consist of a series of extremely short (less than 150 μ sec) VLF pulses, precisely controlled in time, and radiated from a 130 meter vertical antenna. At the receiving site, orthogonal loop antennas are used to separate the two polarization components of the ionospherically reflected skywave signal. One antenna, oriented in the plane of propagation is

(Received for publication 30 August 1976).

1. Lewis, E. A., Rasmussen, J. E., and Kossey, P. A. (1973) Measurements of ionospheric reflectivity from 6 to 35 kHz, *J. Geophys. Res.*, 78:19.
2. Kossey, P. A., Rasmussen, J. E., and Lewis, E. A. (1974) VLF pulse ionosounder measurements of the reflection properties of the lower ionosphere, *Akademie Verlag, COSPAR*, July.
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4. Rasmussen, J. E., McLain, R. J., Capt, USAF, and Turtle, J. P. (1976) VLF/LF Reflectivity of the Polar Ionosphere, 2 March - 3 May 1975, RADC-TR-76-146.

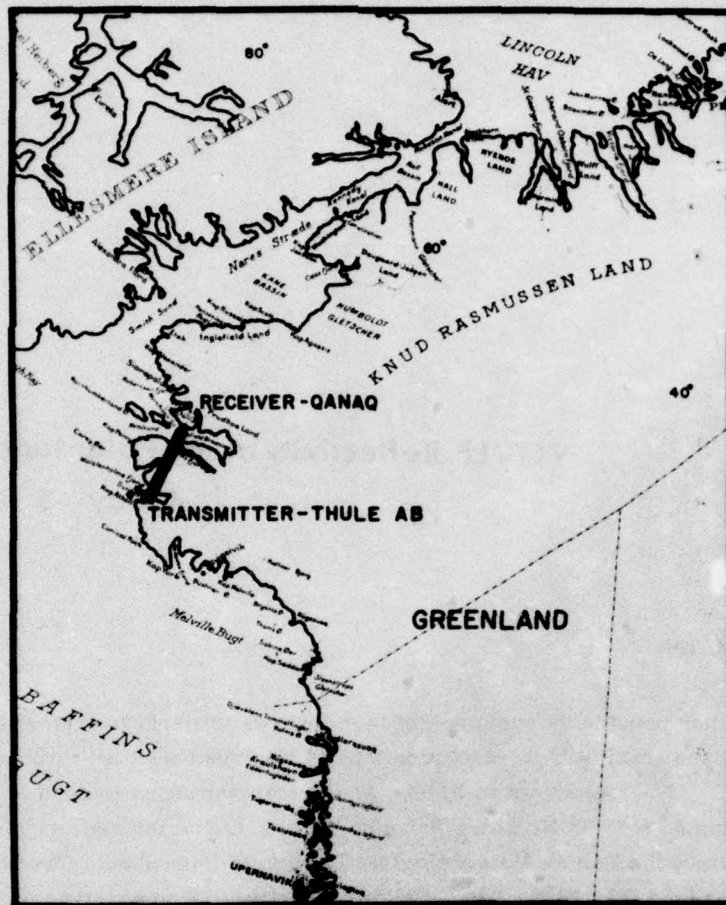


Figure 1. Geometry of the Propagation Path

used to sense the groundwave and the "parallel" component of the downcoming skywave. The second loop, nulled on the groundwave, senses the "perpendicular" skywave component. The signal from each of the antennas is digitally averaged to improve the signal-to-noise ratio of the individual received waveforms before they are recorded on magnetic tape. An example of the observed waveforms is given in Figure 2, where the parallel waveform (Figure 2a) consists of (1) a groundwave propagated pulse of about 100 μ sec duration, (2) a quiet interval, followed by (3) the first-hop skywave signal. The perpendicular waveform is shown in Figure 2b.

Ionospheric reflection parameters are derived by computer (AFGL's CDC 6600) processing of the ground and ionospherically reflected waveforms with allowance made for factors such as ground conductivity, and antenna patterns (see Section 4).

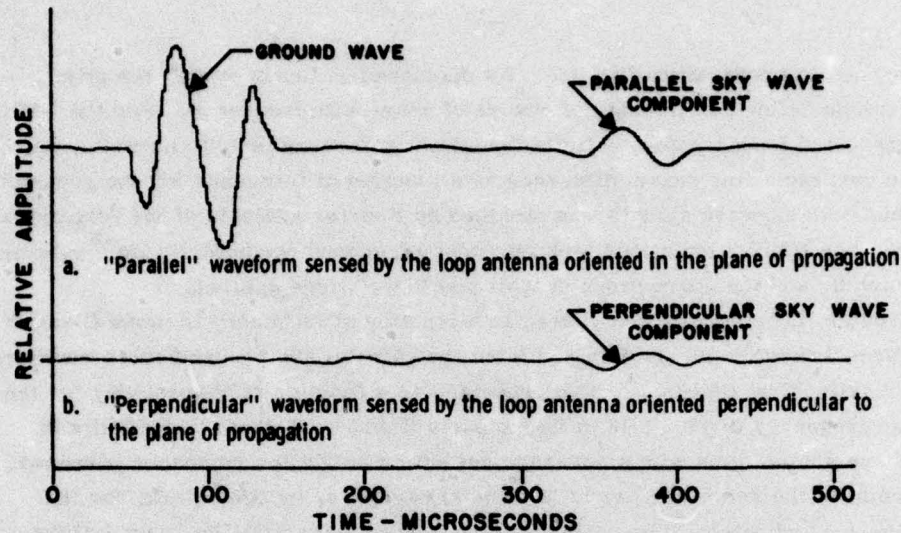


Figure 2. Examples of the Observed Waveforms

Although the data are recorded about once per minute, for this paper the waveforms are averaged into 2-hr time blocks and the resulting information is presented in a weekly format (Figures 3 through 10) as described below.

2. OBSERVED WAVEFORMS

In part A of Figures 3 through 10, a set of averaged parallel and perpendicular waveforms is presented for the time block centered near local noon of the indicated day. Each of these waveforms is comprised of 256 digitally averaged points spaced $2 \mu\text{sec}$ apart. In part B of the figures, the groundwave Fourier amplitudes are shown as a function of frequency. Although the data presented in parts C through L of the figures are generally limited to frequencies in the first, or principal, lobe of the spectrum, information at higher frequencies can be used when sufficient signal to noise conditions exist. There is, however, a frequency range around each spectral null where insufficient signal exists for measurement.

3. REFLECTION HEIGHTS

The group mirror height (GMH) of reflection was obtained by determining the group delay of the skywave relative to the groundwave and attributing this time difference, by simple geometry (assuming a sharply bounded mirror-like ionosphere), to

a difference in propagation distance. As discussed in Lewis et al,¹ the group delay can be defined as the rate of change of phase with frequency. For the GMH data presented in this paper, a finite frequency difference of 1.0 kHz was used, and the corresponding phase difference as a function of frequency for the ground-wave and both skywave signals was obtained by Fourier analysis of the respective pulses. The GMH calculations took into account ground conductivity (10^{-3} mho/m is assumed), and the corrections of Wait and Howe⁵ were applied.

Group mirror heights are plotted as a function of frequency in parts C and D of Figures 3 through 10, as obtained from the parallel and perpendicular waveforms, respectively. The GMH's are also presented as a function of time-of-day for the average frequency of 16.5 kHz in figure parts E and I. The parallel GMH's in part E are shown along with an average reflection height for reference purposes. Each point of the reference height is a weekly average, by time block, for the 7-day period indicated. The corresponding perpendicular GMH's, part I of the figures, are also shown with the weekly average for comparison. Part G gives the average, by time block, for the daily parallel GMH data of part E, and part K gives the corresponding perpendicular GMH averages from the daily data of part I.

4. REFLECTION COEFFICIENTS

Assuming that the ionosphere acts as a "mirror" at the GMH, plane wave reflection coefficients⁶ were obtained by comparing the ratio of the skywave Fourier amplitude at a specific frequency to that of the groundwave, taking into account wave spreading, earth curvature, ground conductivity, path lengths, and antenna patterns including ground image effects.

The reflection coefficient $||R_{||}$ was obtained from analysis of the parallel skywave component and is plotted as a function of frequency in part C of Figures 3 through 10. The $||R_{||}$ coefficient for 16 kHz is plotted as a function of time-of-day in part F along with the average of the indicated week for reference purposes. From the perpendicular skywave pulse, the coefficient $||R_{\perp}$ was obtained and appears as a function of frequency in part D. The 16 kHz $||R_{\perp}$ is shown along with its reference in part J. Parts H and L present the average, by time block, of the daily $||R_{||}$ and $||R_{\perp}$ data presented in parts F and J, respectively.

For certain data points, plotted as asterisks(*) in parts F or J of the figures, the reflection coefficient appears without a corresponding GMH in part E or I. For

5. Wait, J. R., and Howe, H. H. (1956) Amplitude and Phase Curves for Ground-Wave Propagation in the Band 200 Cycles per Second to 500 Kilocycles, Nat. Bur. Stand. U.S. Circ., p. 574.

6. Budden, K. G. (1961) Radio Waves in the Ionosphere, p. 85, Cambridge University Press, London.

these particular data, only the skywave-groundwave ratios could be obtained, as the skywaves were too weak to provide reliable group delay information. The reflection coefficients were therefore estimated using a nominal GHM of 80 km in the calculations. These estimated coefficient values are included in the averages presented in parts H and L, but the assumed heights are not used in the GMH averages shown in parts G and K.

5. SUPPLEMENTARY INFORMATION

For purposes of comparison and interpretation, certain supplementary data are presented. Figure parts M and N give the received VLF phase and amplitude from the 17.8 kHz station NAA (transmitter location: Cutler, Maine), as observed at Thule AB over a 3500-km propagation path. Part O of the figures shows the magnitude of the horizontal component of the polar magnetic field observed with a three-axis fluxgate magnetometer, and part P presents 30-MHz riometer data, an indicator of D-region particle precipitation. These supplementary data were recorded at 30-sec intervals by AFGL's Geopole Observatory at Thule AB; the curves represent the average of 10-min periods. The solar zenith angle is given in part Q of Figures 3 - 10 for the indicated mid-week date.

6. ADDITIONAL COMMENTS

This paper is one of a series.^{3,4} Comments and suggestions for improving its usefulness should be addressed to the VLF/ULF Techniques Branch (ETEE), Electromagnetic Sciences Division, Deputy for Electronic Technology (RADC/ETEE), Hanscom AFB, MA. 01731.

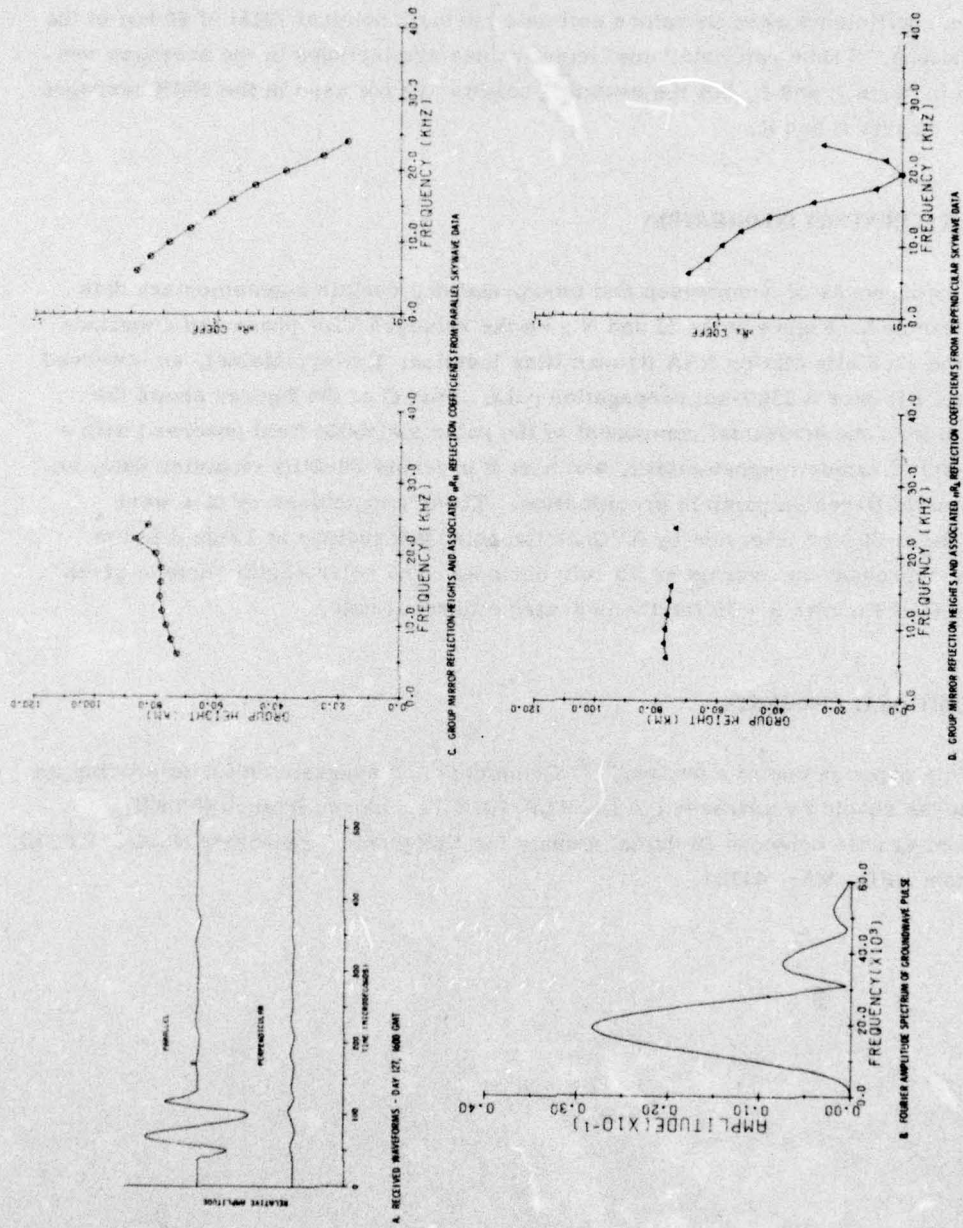


Figure 3. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 124 (4 May) - DAY 130 (10 May) 1975

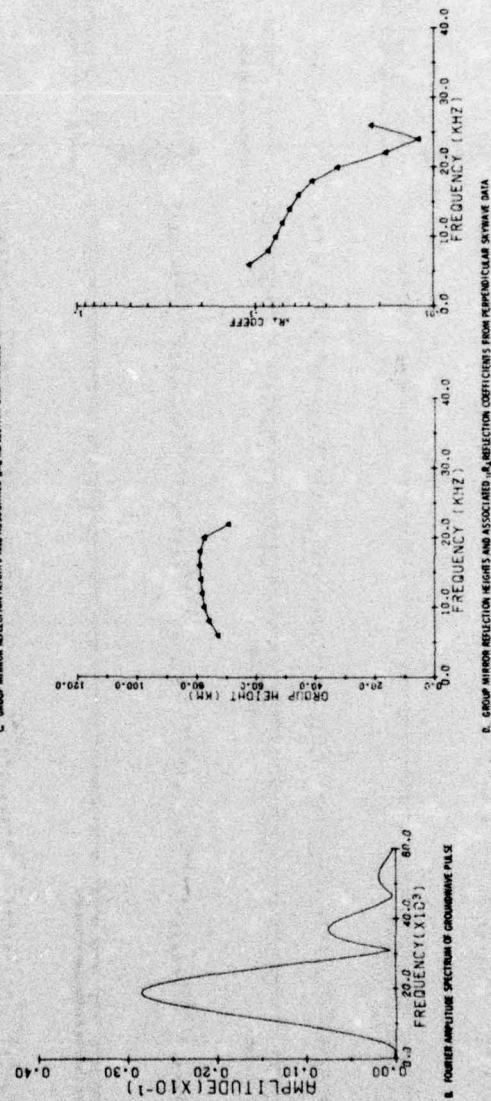
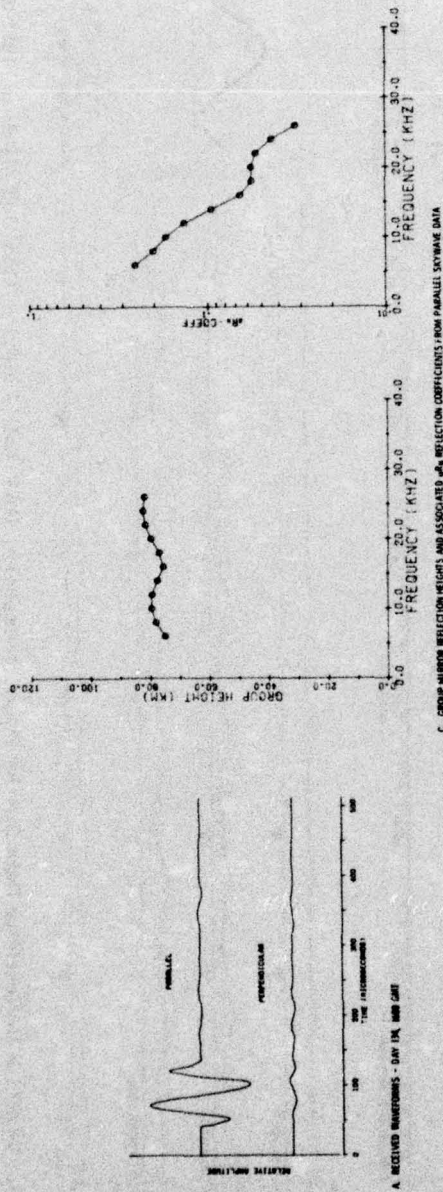


Figure 4. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 131 (11 May) - DAY 137 (17 May) 1975

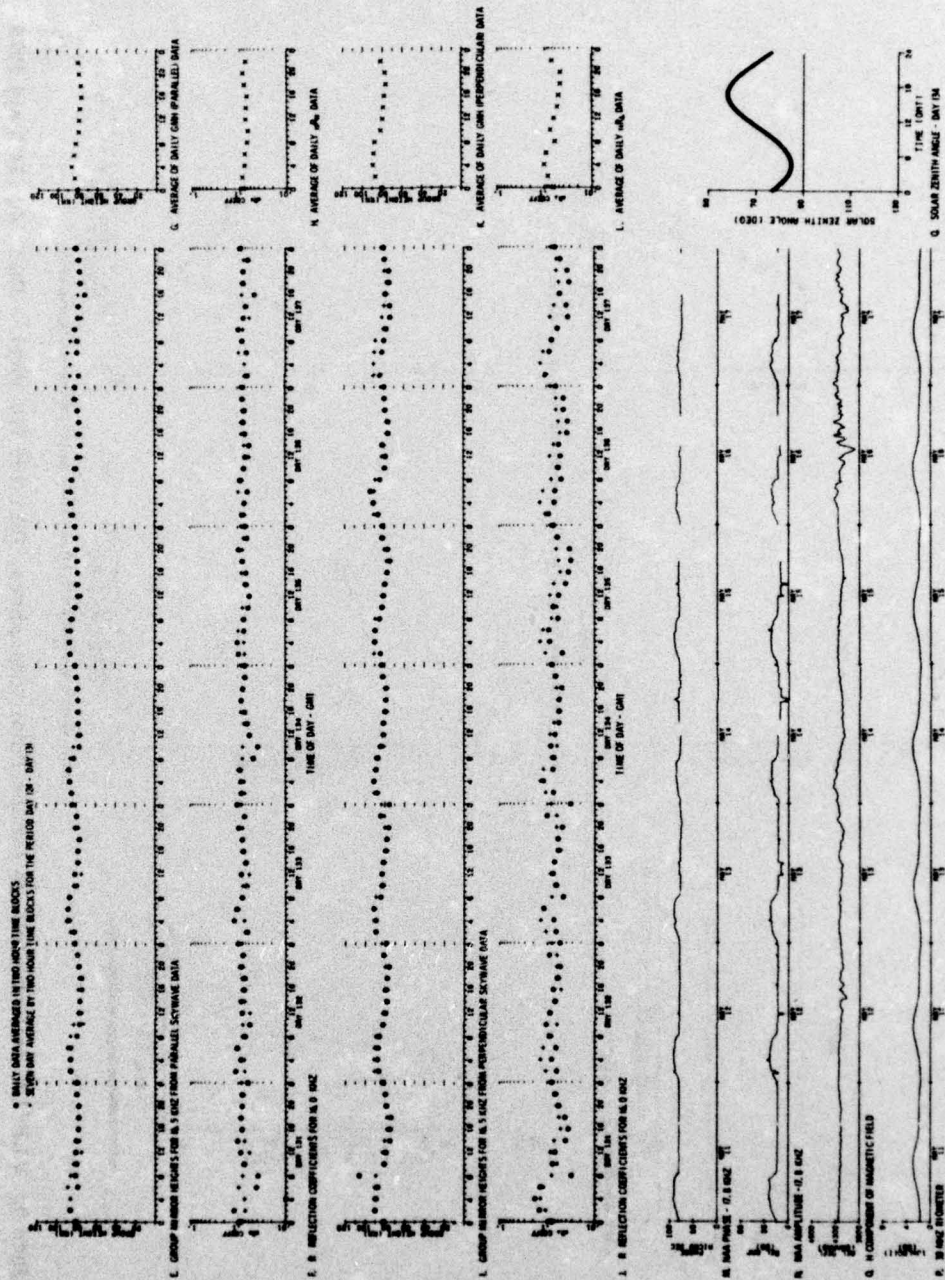


Figure 4. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 131 (11 May) - DAY 137 (17 May) 1975 (Cont)

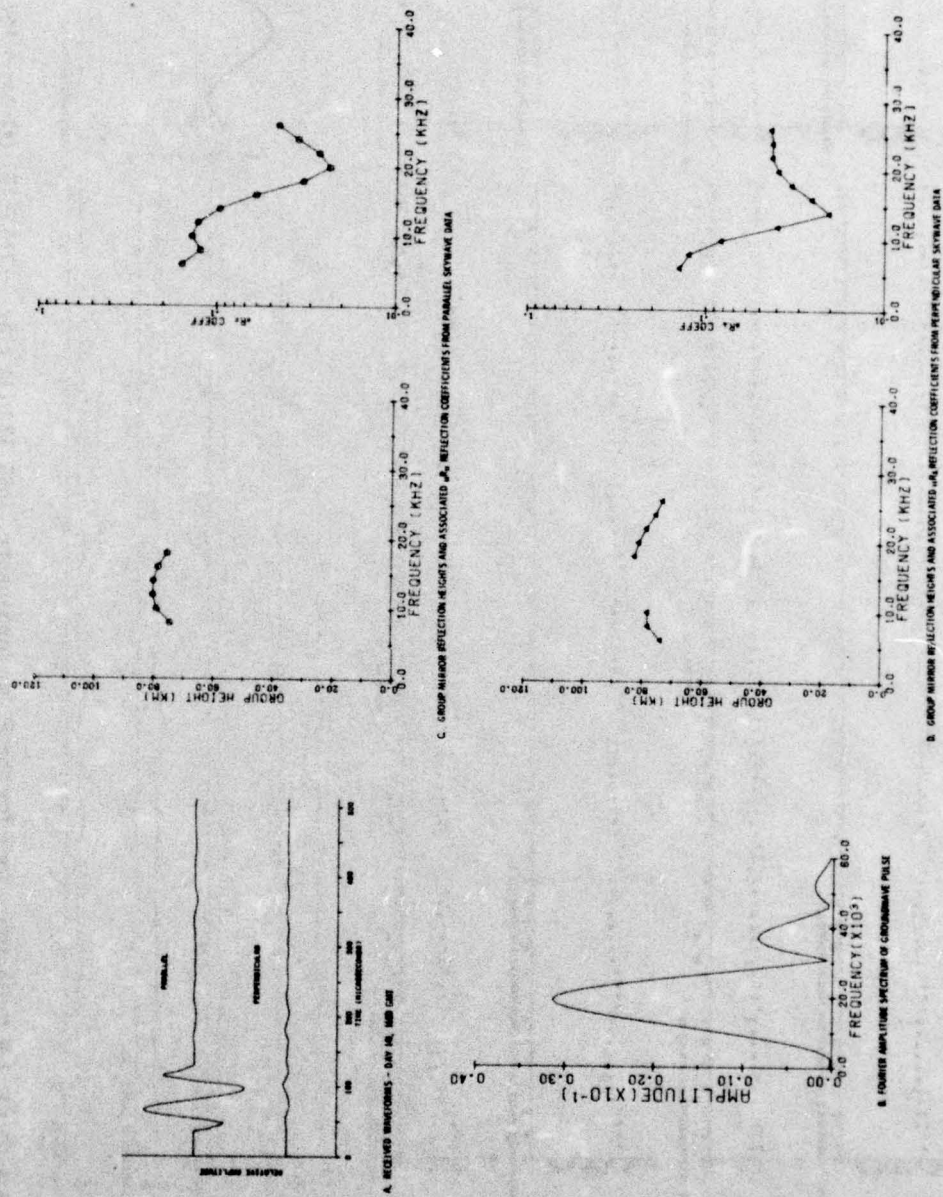


Figure 5. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 138 (18 May) - DAY 144 (24 May) 1975

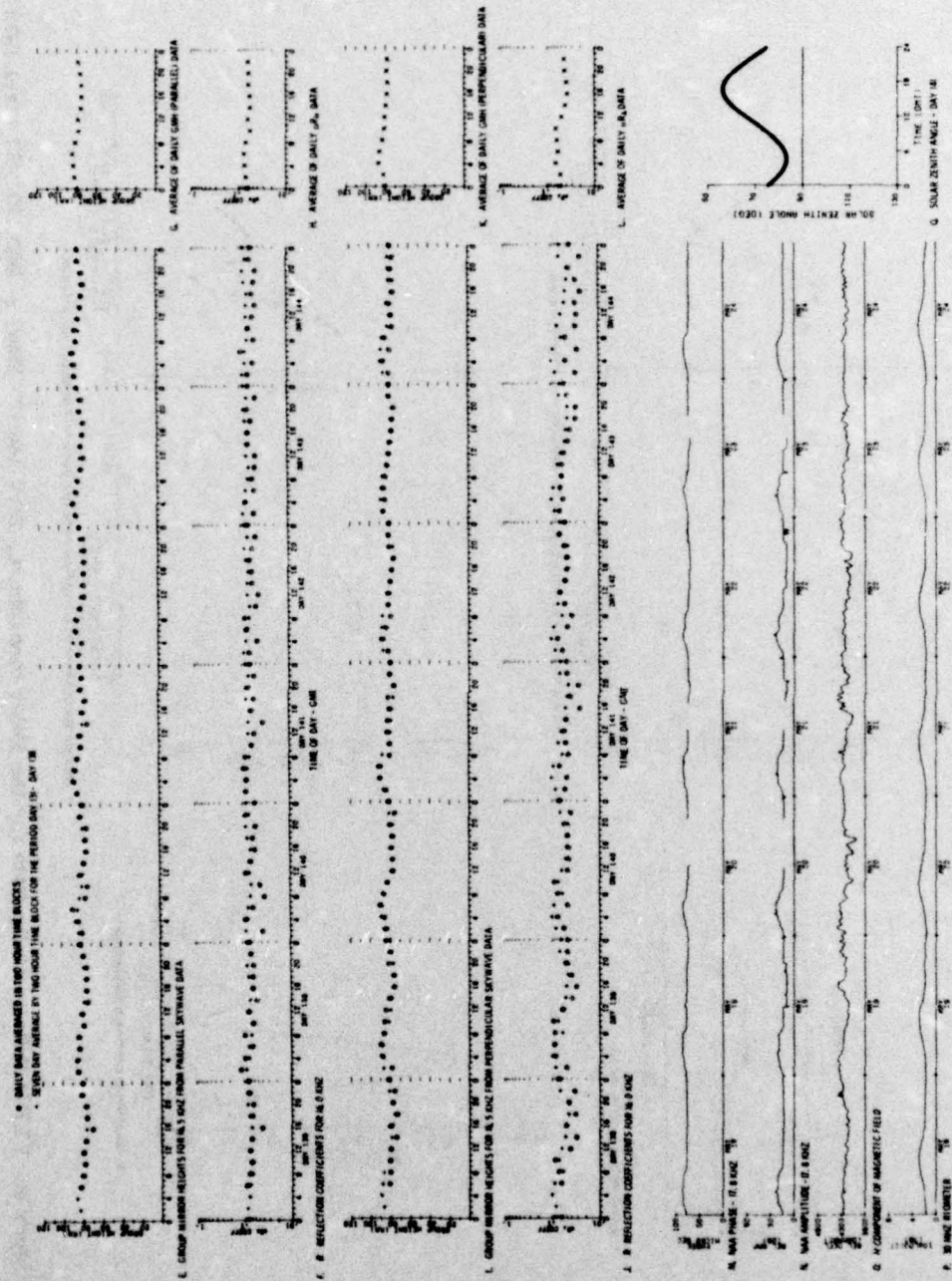


Figure 5. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 138 (18 May) - DAY 144 (24 May) 1975 (Cont)

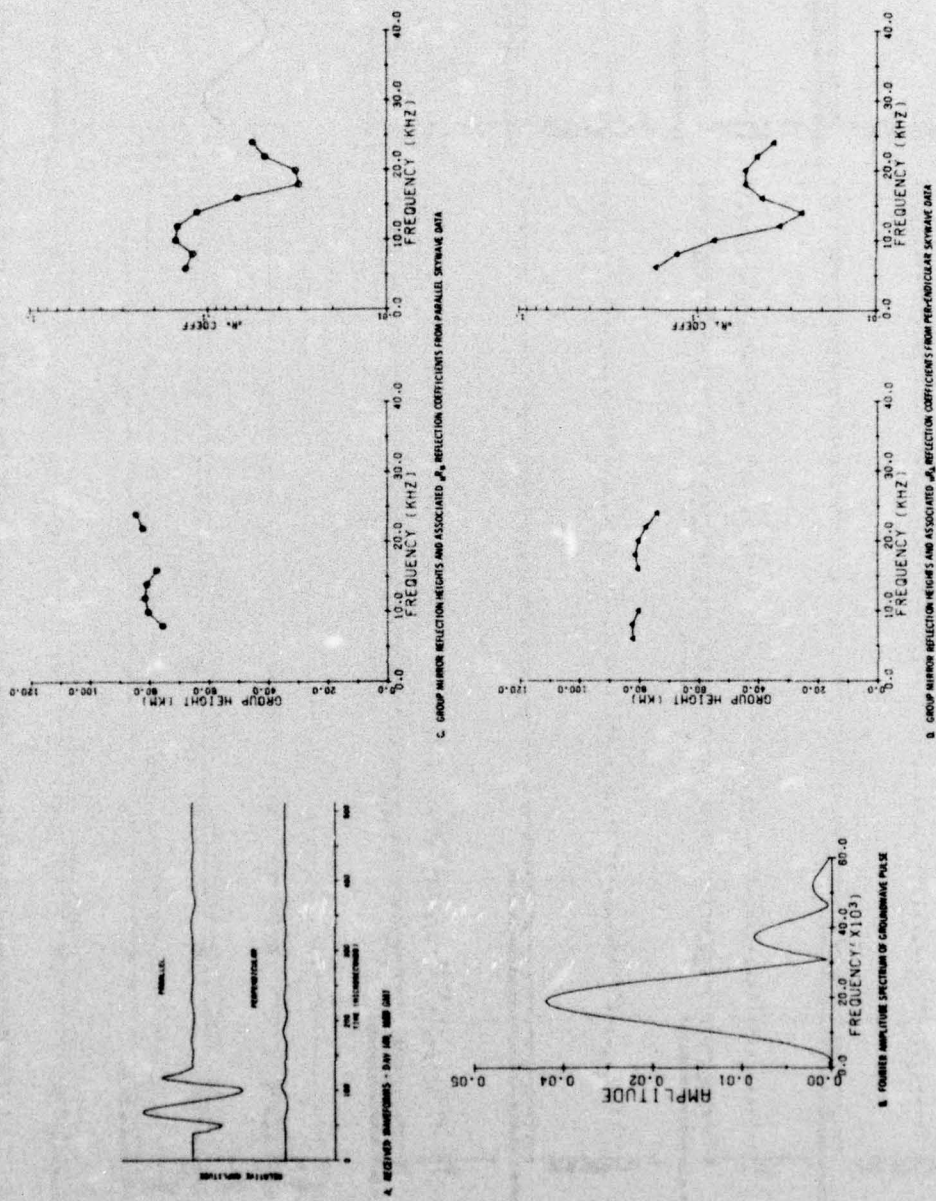


Figure 6. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 145 (25 May) - DAY 151 (31 May) 1975

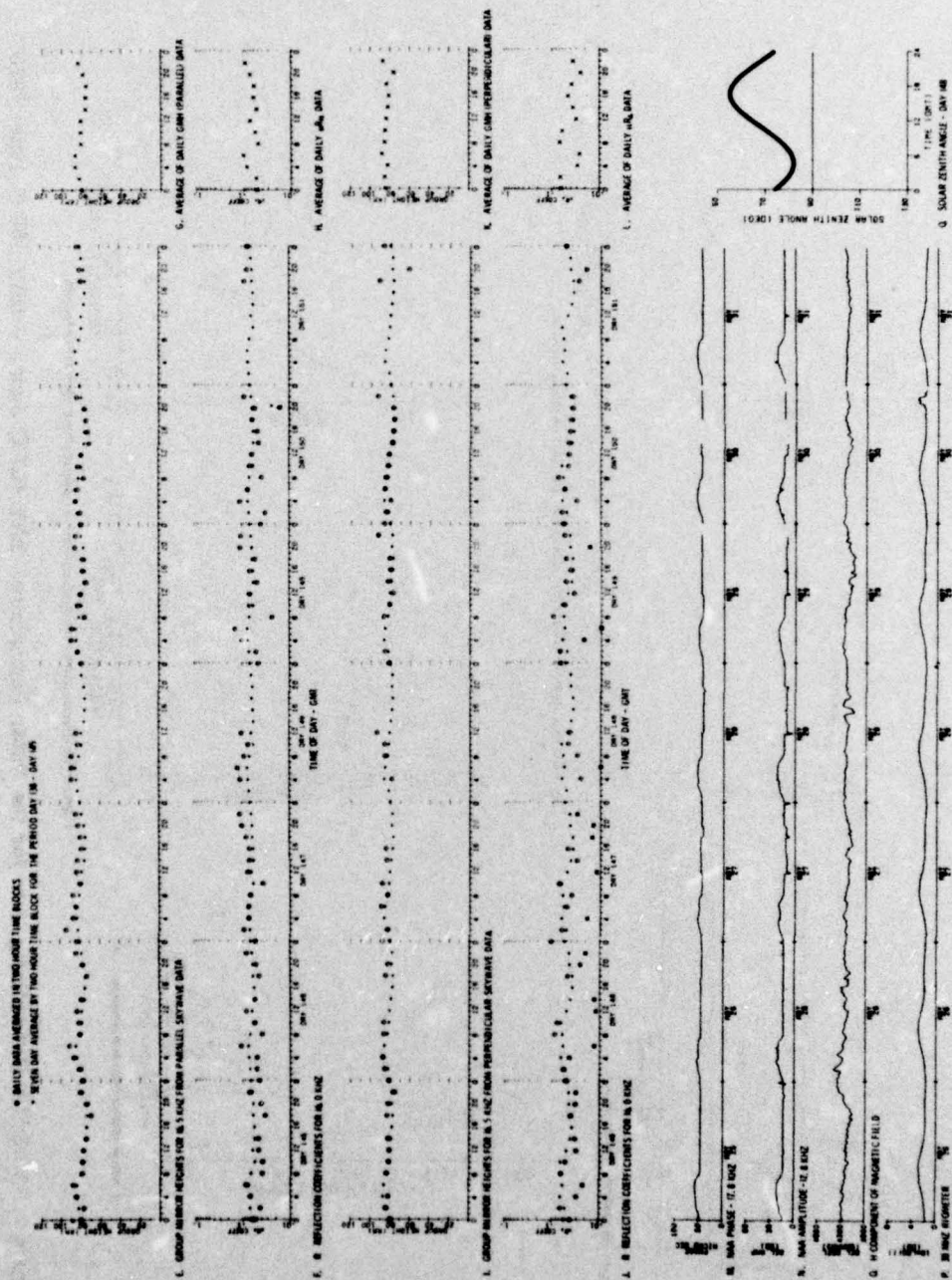


Figure 6. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 145 (25 May) - DAY 151 (31 May) 1975 (Cont)

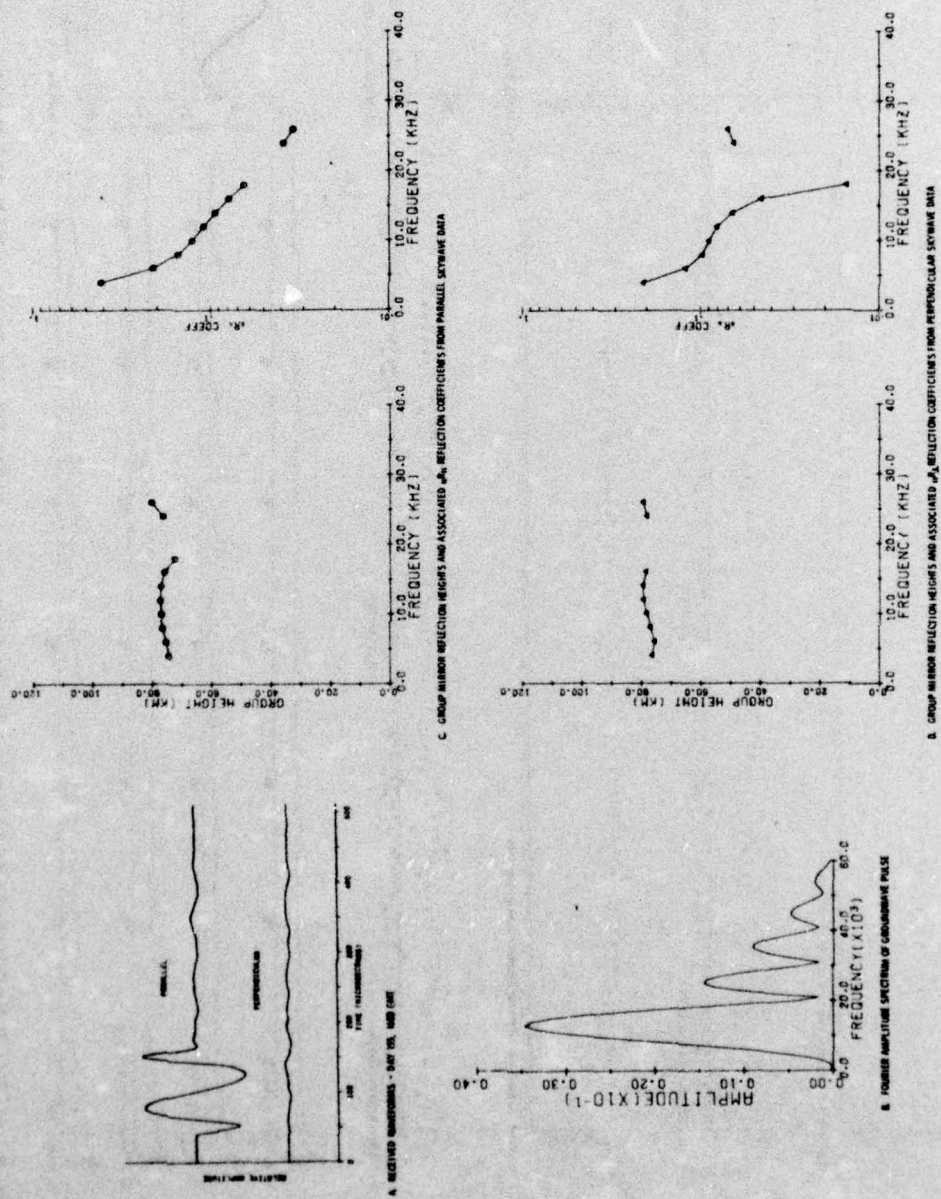


Figure 7. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 152 (1 June) - DAY 158 (7 June) 1975

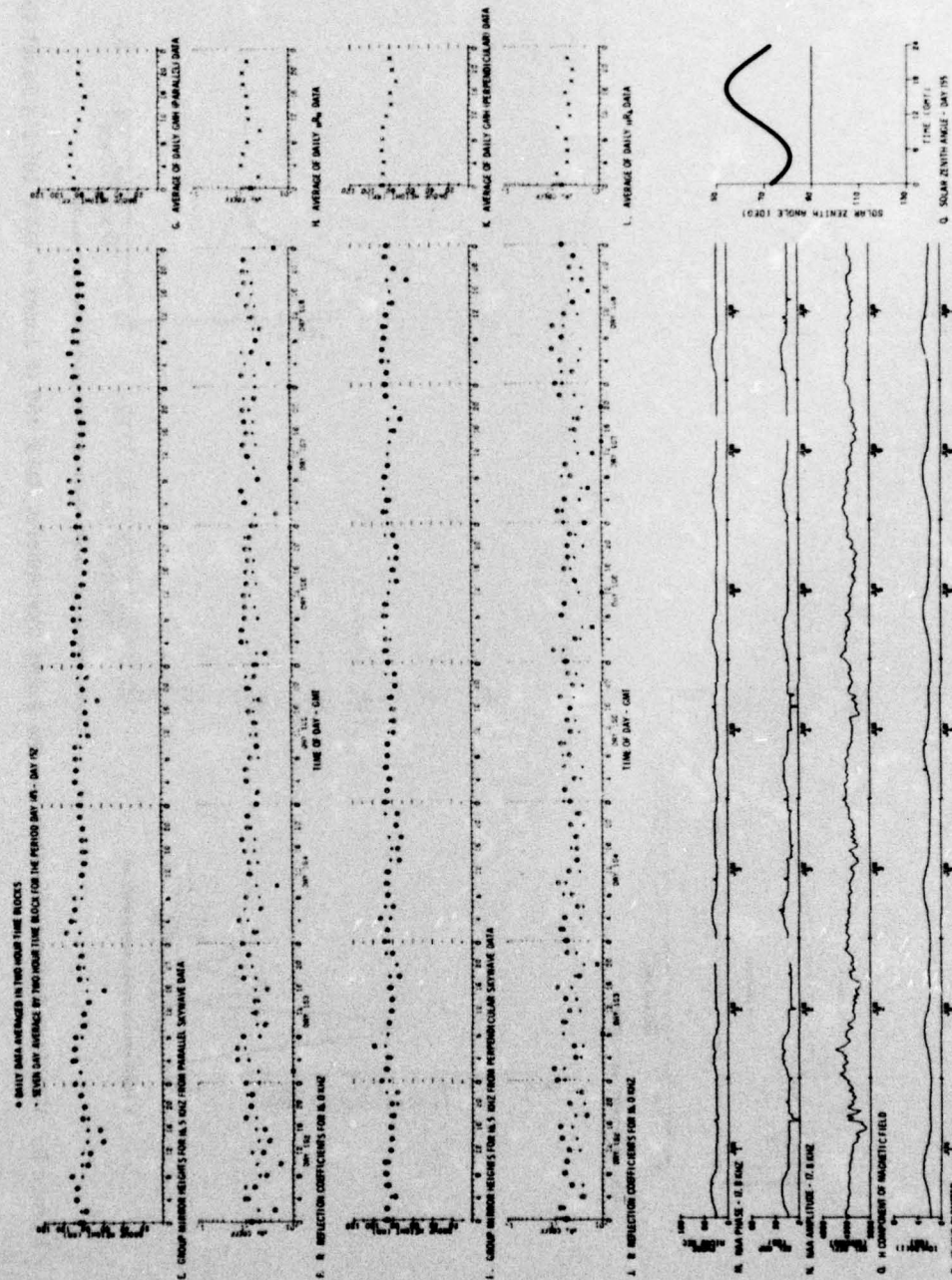


Figure 7. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 152 (1 June) - DAY 158 (7 June) 1975 (Cont)

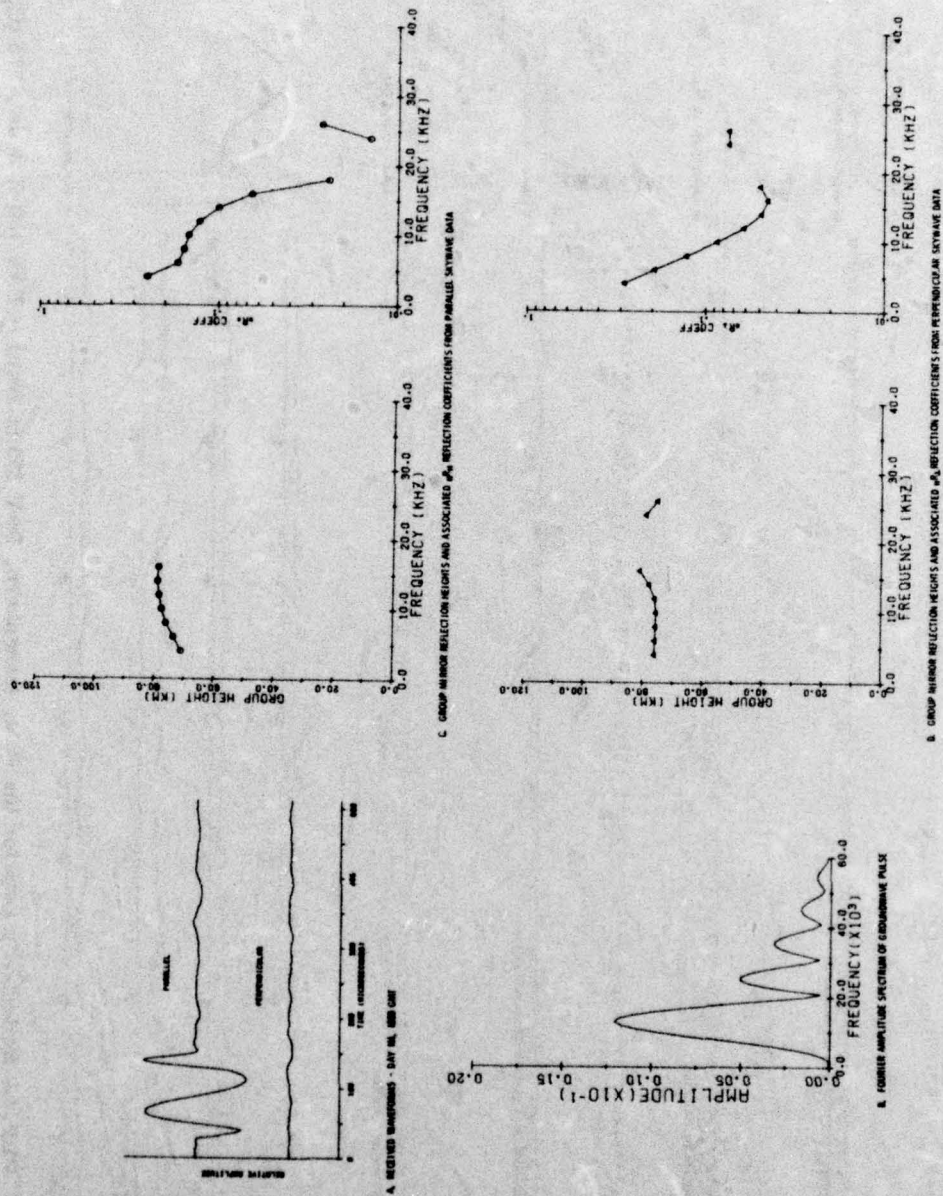


Figure 8. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 159 (8 June) - DAY 165 (14 June) 1975



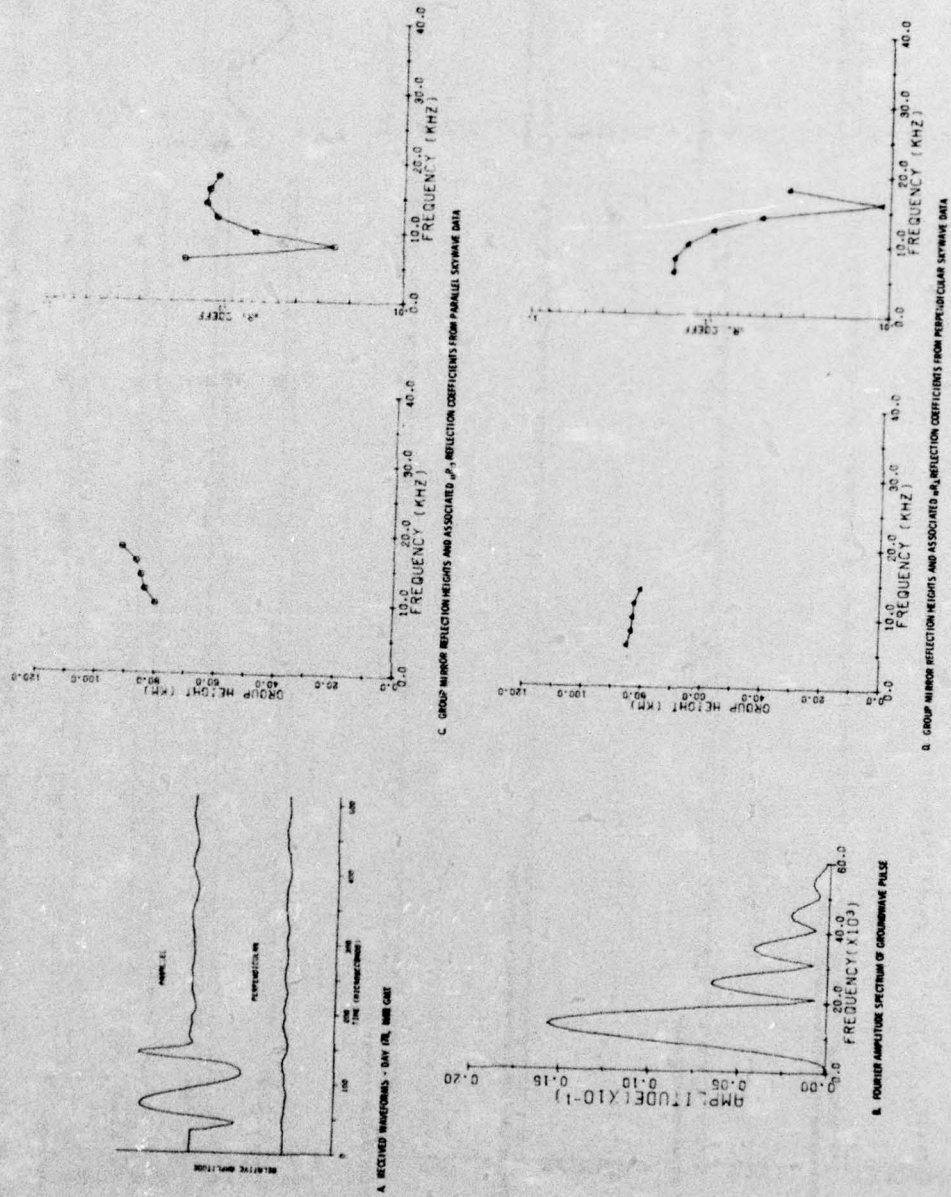
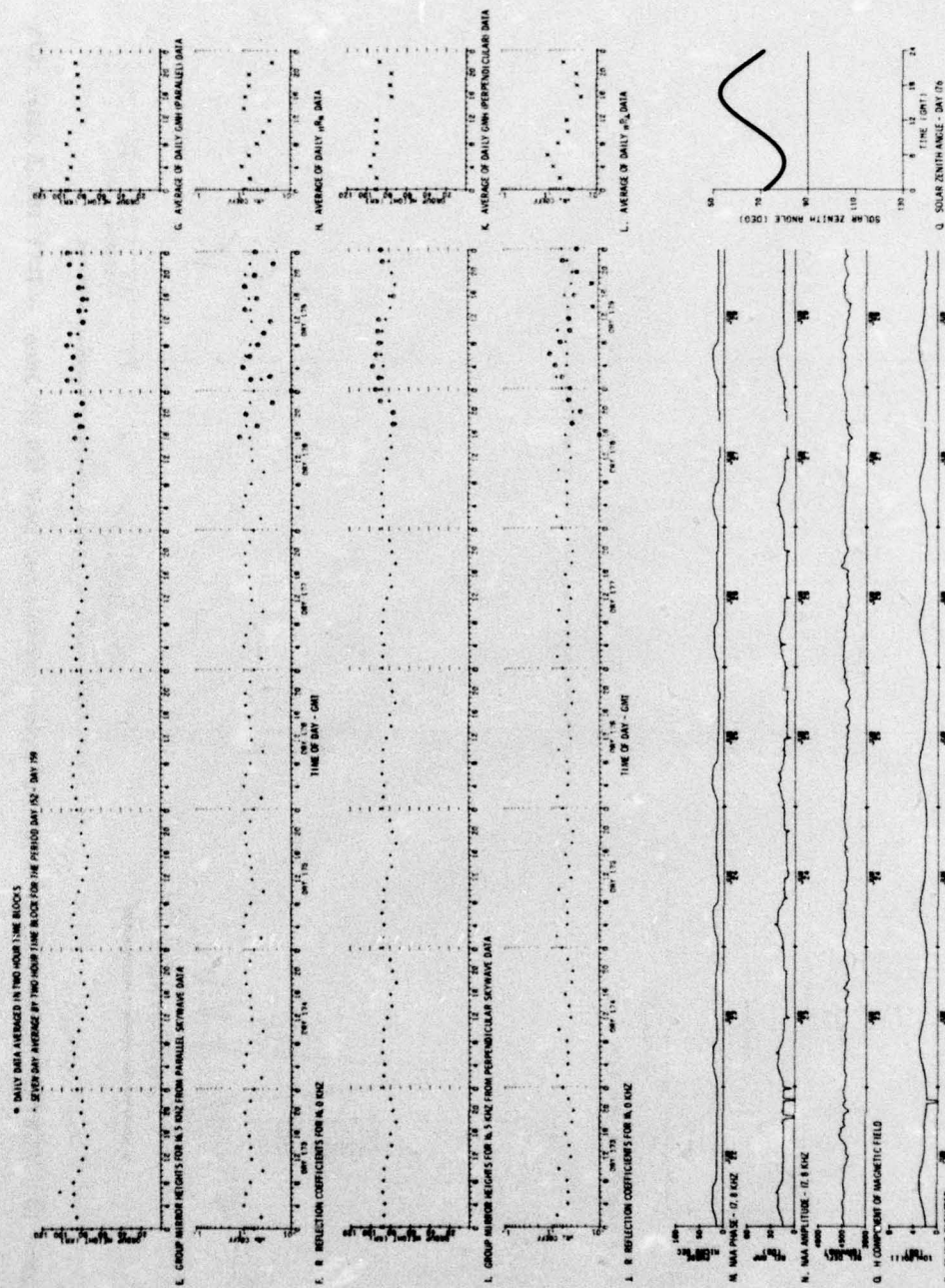


Figure 9. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 173 (22 June) -- DAY 179 (28 June) 1975



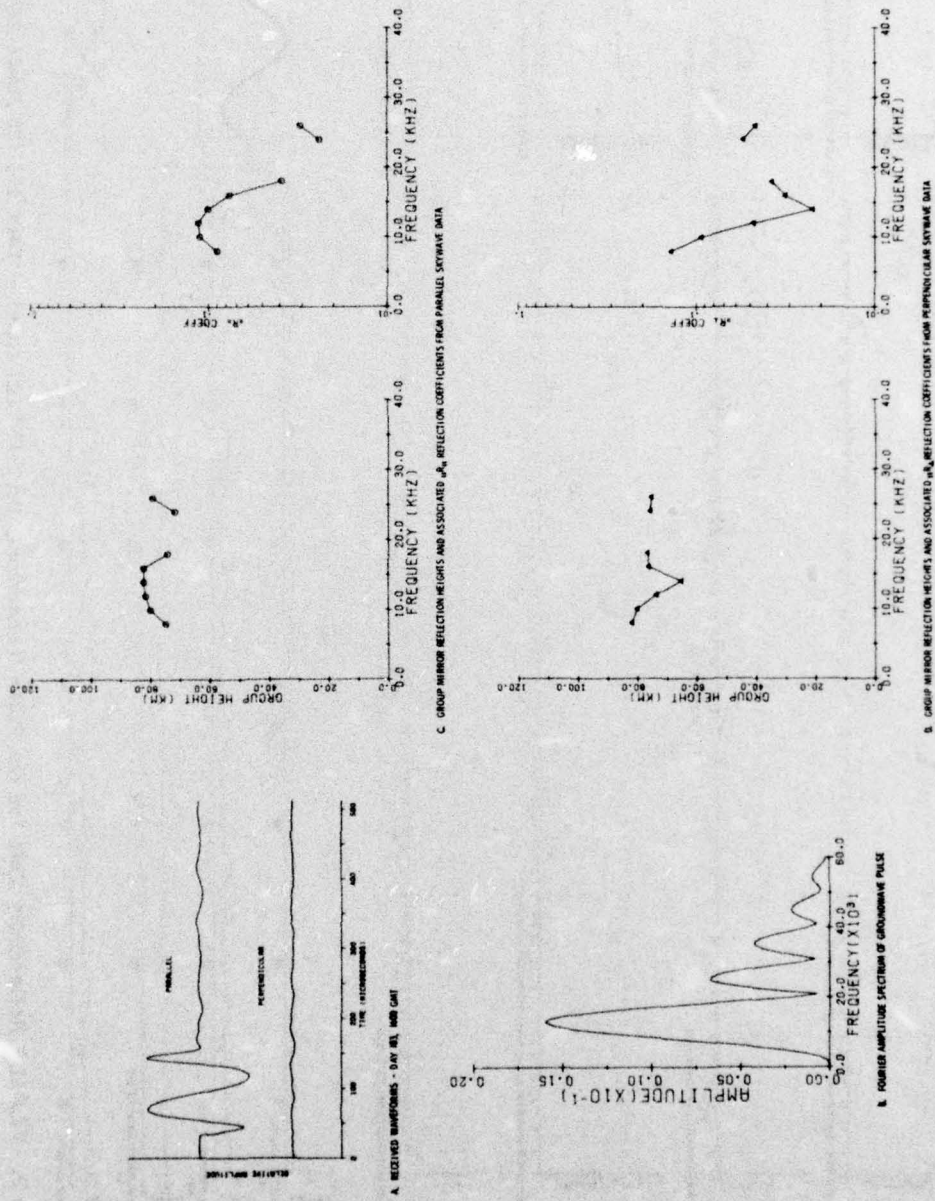


Figure 10. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 180 (29 June) - DAY 186 (5 July) 1975

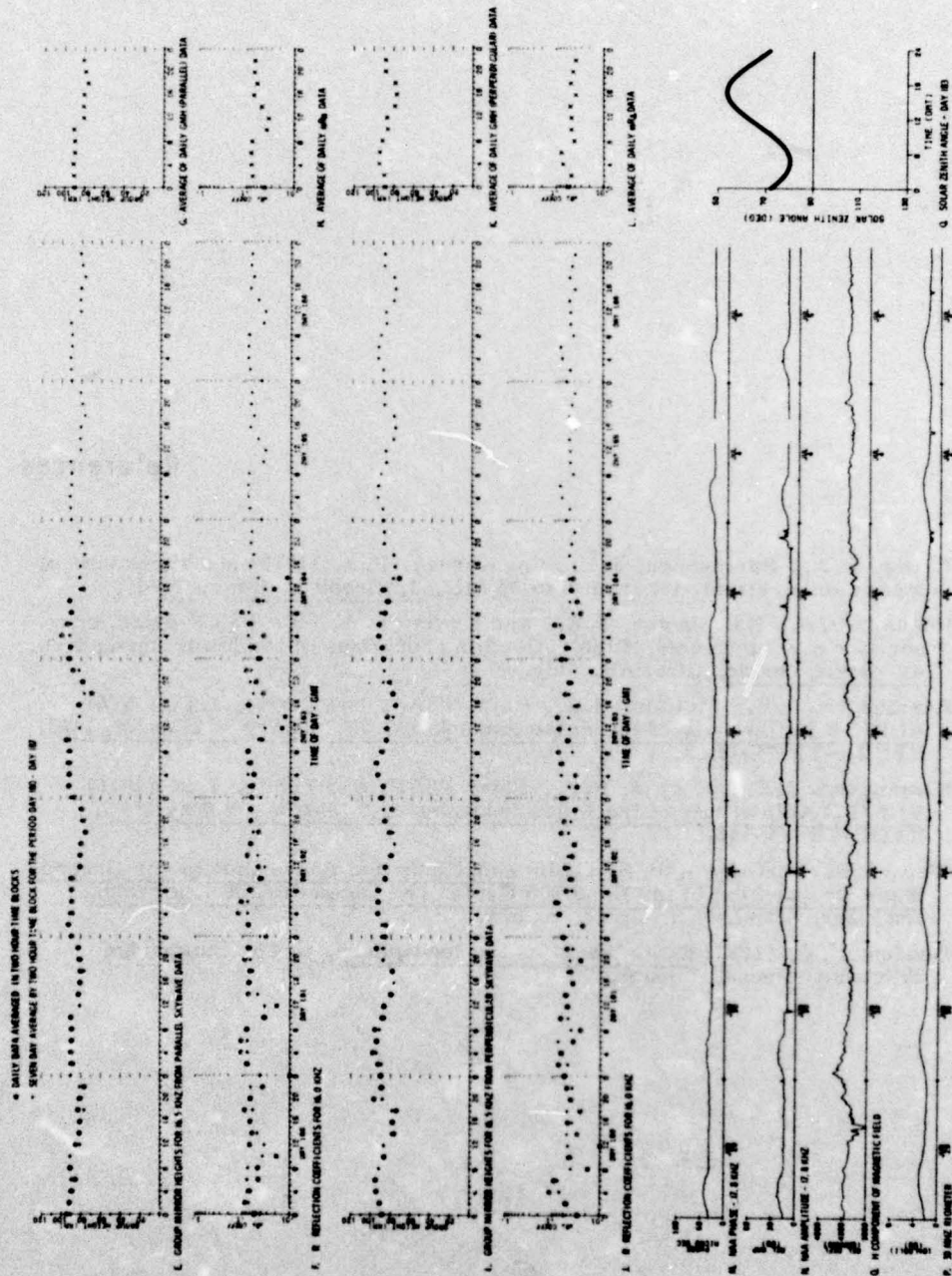


Figure 10. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 180 (29 June) - DAY 186 (5 July) 1975 (Cont)

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6. Budden, K.G. (1961) Radio Waves in the Ionosphere, p. 85, Cambridge University Press, London.